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Europa Lander

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Revolutionary Aerospace Systems Concepts



# EXO-BIOLOGICAL EXPLORATION OF EUROPA ( E<sup>3</sup> )

## Europa Lander

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### Abstract

The search for life outside Earth's protected atmosphere is a compelling testament to the quest by mankind to determine if "we" are alone in the universe. The phenomenal success of the NASA Galileo spacecraft has indicated that the moons of Jupiter, and most notably Europa, may indeed contain subsurface liquid under an icy surface. This speculation of a salty liquid subsurface fuels expert opinions that biological products may exist. The Revolutionary Aerospace Systems Concepts (RASC) effort at Langley Research Center, initiated by NASA Headquarters, pushes NASA and the Aerospace/Science community to target advanced/revolutionary technology usage to provide a Europa Lander concept targeted for completion within the next 50 years. The study effort indicates the use of certain advanced technologies to achieve a subsurface penetrator and liquid explorer in the ~2040 timeframe.

### Study Summary

The study will investigate concept(s) to launch a Spacecraft (Science Mapper & Relay & Lander) or a series of Spacecraft to deliver a Lander (Surface Science Facility) to penetrate the frozen surface and analyze the liquid flows for biological existence and/or processes:

- Utilize, evaluate and indicate Breakthrough and Enabling technology(s) usage.
- Locate a Mapper/ Lander at any longitude or latitude on the surface of Europa:
- Mapper → Conduct surface mapping and characterization (~1-2 months); refine surface depth location targeting; descend to the surface for Lander operations
- Penetrate through the frozen surface to explore the surface and liquid subsurface; lifetime of ~2 years
- Provide a surface/subsurface infrastructure & capability for

science data and video  
communications back to Earth  
(DTE or Relay)

- **Place a Science Relay Orbiter (SRO) around Jupiter to support Europa communications; Provide relay communications & coverage for a lifetime of about 2 years**
- **Utilize Decision Tree Software to generate and show concept option paths; categorize the risks, mission success criteria and cumulative costs associated with various path options and concept options.**

### Requirements

#### Level 1 requirements (GOALS)

- The mission **shall** launch a Spacecraft (Relay/Mapper/Lander) to a Jupiter Orbit; **shall** deliver a Mapper/Lander (Surface Science Facility) to Europa surface; **shall** penetrate the frozen surface and descend to the liquid subsurface boundary; **shall** search for evidence of biological existence and /or processes
- The mission **shall** locate a Mapper/Lander at any longitude or latitude on the surface of Europa:  
**Mapper: Shall** conduct surface mapping and characterization (~1-2 months) prior to descent to achieve final surface location targeting;  
**Lander: Shall** use a Cryobot to burrow (via melting) through the frozen surface to explore the subsurface and a HydroBot to explore the potential liquid subsurface ocean; **Shall** provide an infrastructure & capability for science data return and communications with Earth
- Cameras **shall** be included on Lander and submersible

- The mission **shall** provide relay communications support of science data and camera pictures; with potential to locate a relay vehicle outside main radiation areas around Jupiter
- The concept **shall** utilize, evaluate and indicate breakthrough technology(s) usage necessary to accomplish the mission

### Lifetime

The total mission lifetime shall be 4-6 years as a minimum. From launch to cruise to arrival, this duration shall not exceed ~ 4 years. Once influenced by the Jovian system, the segment lifetimes are as follows:

- The Relay (Science Relay Orbiter) **shall** survive for up to ~2.2 years
- The Mapper/Lander **shall** survive on Europa surface for up to ~ 2.2 years
- The CryoBot/HydroBot **shall** survive for a period of ~ 2 years, with the HydroBot operation lasting only ~1 year.

### Background

The Jet Propulsion Laboratory has studied missions to Europa for some time, and has a planned a Europa Orbiter mission scheduled for launch around 2008. Although JPL's Europa Program forecasts a series of missions to this one of Jupiter's moons, these precursor missions are small in scope and objectives in the RASC timeframe. The RASC study will focus on the complex mission to investigate potential subsurface liquids for possible evidence of biological life processes, while identifying near term funding efforts necessary to provide advanced technologies to accomplish the mission. JPL's current Europa Program schedule estimates a turn of the century mission to explore the subsurface liquids on Europa, whereas the RASC effort

accelerates this type of mission to the 2040 timeframe.

While JPL's focus has been on relatively short term mission life once the Europa system is encountered, another feature of the RASC concept calls for a Europa Lander that presses the technology efforts to sustain a 2 year surface & subsurface exploration mission.

### **Approach**

The Europa Lander mission (aka, E<sup>3</sup>) will contain mission segments and architectures designed to provide a minimal radiation exposure approach trajectory and operations for a Europa Lander. Studies will focus on trajectories and segment architectures to place the Mapper/Lander on the surface of Europa, support pre-landing mapping and precision landing site selection, and maximum communications support for the landed mission duration of at least two years:

#### **1. Finalize Mission concept(s) for a Europa Lander**

- Trajectory options and propulsion technology concepts ( High versus low thrust)
- Concepts for Orbiter support, radiation mitigation
- Concept for Orbit, Descent and Landing ( Architecture and Concept )
- Detail communications coverage as a function of Landed location and Orbiter locations
- Outline landed operations and architecture for Surface/subsurface science investigations
- Listing of trade studies that need to be investigated to firm up concept and technology usage
- Analysis Results for Resource utilization

#### **2. List advanced technologies as ranked and defined for Europa Lander mission**

- Decision Tree results and modification that show multiple path options, assigned success/risk metrics, and mission concept timeline
- Methodology for Ranking, roadmap to cost allocations and schedule
- Cross cutting technology usage tie-into other future missions

#### **3. Provide Simulated visualization of Key mission phases, based upon analyses results/data**

- Use of post-simulation data processing to simulate actual mission phases and activities

### **Implementation**

The idea of a mission concept to place a penetrating Lander on the surface of Europa involves some coordination and planning to utilize the results from previous Europa missions, then placing the Lander on the surface where the frozen surface is at it's thinnest point. For this study, the target depth is 3 kilometers or less.

Because of the distance and harsh radiation of the Jovian system, the present study places the spacecraft (Relay / Mapper / Lander) into a Jupiter orbit as a staging point, then allows the Mapper/Lander to continue on to Europa.

Some fundamental techniques are used where the spacecraft is launched directly from Earth to a Jupiter arriving trajectory (Holmann transfer), then a placement into an elliptical orbit around Jupiter (at a distance to avoid extreme radiation), where the Mapper/Lander deploys after some period of time.

### Timelines

Due to the RASC objective to outline a concept for a 30-50 year timeframe, the Europa Lander concept targets an approximate launch date of ~ 2034-2035, and the arrival date to a Jupiter orbit is between 3-3.5 years later. Below is a simplified schedule of events.

**Table 1 – Timeline for E3 in RASC 2001 timeframe**

Event/Date	2035	2036	2037	2038	2039	2040	2041
Launch Europa Lander (Single Launch)	▲						
Cruise to Jupiter (2-3 years)	◆	—	—	◆			
Jupiter Arrival –Staging Orbit (~ 1-2 months)				◆◆			
Mapper/Lander release/cruise to Europa and Relay re-designation in Jupiter Orbit (1-2 weeks)				◆◆			
Europa Orbit insertion & 1-2 month mapping phase (~1-2 months)					◆◆		
Mapper/Lander descent & touchdown (around 2 <sup>nd</sup> qtr 2039)					▲		
Cryobot deploy and surface ice penetration (1 year to penetrate)					◆	◆	
Hydrobot activation and 'life search' science (1 year to search for life)						◆	◆

### Strategies

Due to the large amount of payload that needs to be delivered to the surface of Europa, an efficient propulsion system is required in order to keep the launch mass reasonably low. Another important driver is the desire to spend as little time as necessary in the vicinity of Jupiter, in order to avoid Jupiter's harsh radiation environment. The latter requirement excludes the use of low-thrust propulsion systems in the neighborhood of Jupiter. Of course, high-thrust capability will be required also for the actual landing on Europa. Nuclear Thermal Propulsion is seen as a good candidate to meet the above needs. In particular, NTP is very fuel efficient, has high-thrust capability, re-start capability, and is throttleable. Hence one single NTP system can serve for all legs of the mission. In

addition, NTP systems can also be designed to provide on-board electrical power.

In the following, the envisioned mission architecture and time line is laid out in more detail:

1. Launch from Earth into nuclear safe Earth orbit. This phase takes an insignificant amount of time on the order of one day.

2. Application of high-thrust velocity increment for injection into a direct trajectory to Jupiter. Transfer vehicle has bimodal Nuclear Thermal Propulsion system (NTP), i.e. nuclear reactor provides power for propulsion system and generates moderate amounts of electric power (around 1 kW). The specific impulse of NTP is around 1,000 seconds. This phase takes an insignificant amount of time on the order of one day.
3. Transfer to Jupiter consists of coasting with minor trajectory corrections; no planetary flybys are used. This phase will take a significant amount of time. If the impulse at departure from Earth is chosen as small as possible (for fuel saving purposes), then the transfer

can take up to nearly 3 years. Faster transfers can be achieved at the expense of higher fuel consumption. Given the good fuel efficiency of NTP, the penalty in fuel consumption should not be severe. It should be noted, however, that transfer time is not of the essence as it takes place outside Jupiter's radiation belt. A precise study of the balance between transfer time and fuel consumption is reserved for a follow-on study.

4. Application of high-thrust velocity increment for capture into circular orbit around Jupiter with semi-major axis of around 20  $R_J$ . ( $R_J$  denotes the radius of Jupiter). Propulsion system is identical to the NTP system used for the interplanetary transfer. This phase takes an insignificant amount of time on the order of one day.
5. Mapper/Lander maps Europa's surface for one to two months. Data will be used to determine precise target landing site. Note that the orbit is chosen such that the spacecraft remains outside Jupiter's radiation belt at all times. Hence, time is not of the essence for this phase (except for considerations on hardware lifetime).
6. Once target landing site is determined, Mapper/Lander separates from Relay Satellite. The intention is for the Relay Satellite to transfer to an orbit suited to relay communications between the surface of Europa and the Earth. For the Lander, the intention is to initiate transfer to Europa using the same NTP system used for the interplanetary transfer. The exact coordination and sequencing of the Relay Satellite's transfer to its desired final orbit and the lander's entry descent and landing (EDL) operations needs to be fine-tuned to guarantee continuous communications coverage during the Lander's EDL operations. This activity is reserved for a follow-on study.
7. Mapper/Lander applies high-thrust velocity increment using NTP and transfers to Europa. The thrusting part of this phase takes an insignificant amount of time in the order of one day. The coasting arc of this phase takes less than 4 days.
8. Mapper/Lander applies high-thrust velocity increment using NTP for capture into 100 km circular orbit around Europa. Note that any inclination can be achieved through minor changes in the transfer from 20  $R_J$  Jupiter orbit to Europa. The capture phase takes an insignificant amount of time in the order of one day.
9. Mapper/Lander lands on Europa using the same high-thrust NTP system used for all other transfers of Mapper/Lander. This phase takes an insignificant amount of time on the order of one day.
10. Mapper/Lander deploys Cryobot. Cryobot drills through Europa's ice surface until liquid ocean is reached underneath the ice. During descent to the liquid ocean, cryobot deposits communication relays in the ice to enable communications with Mapper/Lander. Throughout the drilling period, Mapper/Lander performs its own surface experiments and relays information back to Earth (directly or through the Relay Satellite). Mapper/Lander also relays information (system health, position, depth, etc.) obtained from Cryobot back to Earth. This phase takes up to 1-2 years.

11. Once liquid ocean underneath Europa's ice is reached, Cryobot releases tethered submarine. Submarine searches for life and relays information back to Cryobot. This phase is intended to take as long as possible. It ends when the submarine and/or other systems run out of resources (power, etc.).

### **Architecture, Mission, and Element Concepts**

#### **Launch Vehicle(s)**

The most critical drivers for the choice of launch vehicles are

1. The large mass of the spacecraft/delivery system
2. The requirement to launch into a nuclear-safe orbit.

The in-space propulsion system has not been defined to sufficient detail to determine a specific launch vehicle capability requirement. The Earth-to-orbit lift requirement is certainly beyond anything readily available today. However, the mission may be reconfigured to relax this requirement. For instance, launching the Mapper/Lander and the Relay Satellite as two separate units may be advantageous, since the Relay Satellite is a much smaller unit than the Mapper/Lander. Also, the assumption that the Relay Satellite must be nuclear needs to be re-examined, since non-nuclear spacecraft are much easier/cheaper to launch than nuclear spacecraft. Future trade studies to determine the maneuvers required by the Relay Satellite near Jupiter to achieve global coverage during descent and landing of the Mapper/Lander, may show that a purely chemical propulsion system is preferable for the overall mission of the Relay Satellite. However, to decide

whether the Relay Satellite can be completely non-nuclear, the power requirement for the RF transmissions must be defined. If such trade studies show that the relay satellite needs a nuclear power source to provide the required levels of on-board power over an extended period of time, then a combined nuclear power and propulsion system may be the most efficient concept.

#### **Spacecraft Bus & Cruise Vehicle**

#### **To be included in future RASC studies of similar types of missions**

#### **Relay Orbiter**

In the baseline mission architecture, it is envisioned that a Relay Satellite rides "piggyback" with the Mapper/Lander all the way to a circular Jupiter orbit of 20  $R_J$  semi-major axis. From there, only a moderate amount of delta-v is required to insert the Relay satellite into its final orbit around Jupiter. However, additional maneuvers of the Relay Satellite may be required before that to enable continuous coverage during EDL of the Mapper/Lander. Trade studies need to be conducted over the antennae sizes, the power at which radio signals are transmitted, and the on-board power storage system / power generation system. These trade studies, and the careful analysis of the maneuvers required by the Relay Satellite to achieve continuous coverage during the Mapper/Lander EDL, will determine the basic configuration of the Relay Satellite. Decisions will determine whether the Relay Satellite should be launched and transferred together with the Mapper/Lander or as a completely separate spacecraft. The



implications of duplicating systems on both spacecraft, and the cost of an extra launch, must be considered in such studies.

For RF communication performance analysis, the Relay Orbiter orbits Jupiter in the 20N orbit (note that N is defined as an integer multiple of Europa's orbital period and N varies from 2 to 200 for communication coverage studies. A telemetry data rate of 250,000 bps is assumed and it is further assumed that the relay satellite uses the same antennae for transmitting and receiving. The telemetry frequency is 8.45 GHz and the command frequency is 7.19 GHz. The satellite acts as a store and forward relay. While the Earth is occulted the telemetry data is transmitted to the relay satellite which stores the data until direct communication between the Earth and the Europa Lander is re-established at which point the relay satellite's antenna is pointed toward Earth and the stored data is transmitted back to Earth. This configuration has the benefit of requiring a single antenna. The final configuration with a 135W power amplifier and a 2.6 m dish has been chosen. A more economical choice may be possible using either optical communications technology or by using several small satellites flying in formation and operating as a phased array.

### **Mapper/ Lander**

The Mapper/Lander vehicle must be capable of performing both target and acquisition resolution mapping while in a ~1-2 month polar orbit of Europa, then initiate a surface descent phase. The Mapper portion of the spacecraft is responsible for fine tuning the landing area of interest and must be able to withstand the extreme radiation and thermal environment posed by a roughly 100 km orbit altitude. After a defined period of target area resolution and

mapping (~1-2 months), the Mapper/Lander then descends to the surface of Europa where it then performs the Lander/science phase of the mission.

### **Surface Lander**

The Lander is comprised of three segments:

- Landed communications relay segment; surface camera viewing and surface science exploration
- Cryobot deployment, surface penetration, through-the-ice communications relay and science investigation phase
- Hydrobot deployment and subsurface liquid exploration/science phase, including camera pictures of navigation and subsurface features

The Lander segment becomes a communications relay and gateway with Earth. It shall consist of communications that allow transfers of data and pictures to either the Jupiter Orbiting Relay or directly with earth's DSN communications Network. It includes a suite of instruments and camera(s) to investigate Europa's surface anomalies, features, and active surface movements.

### **Cryobot**

A Cryobot is a vehicle which moves through ice by melting the ice wall directly in front of it, taking measurements of the encountered environment, and sending the collected data and/or images to the surface Lander for transmission back to Earth. It is a new tool in development designed to penetrate ice and avoid any contamination of the environment; it is also a measuring instrument to reveal the internal structure and composition of the ice as well as the

inner glacial and subglacial environment: including its physical, chemical and biological characteristics. Fully developed, the cryobot will be a tool of exploration, a tool to be used by many scientific disciplines, foremost glaciology, but also by many other earth and planetary science fields.

The Cryobot must be capable of communications with a surface Lander to relay science data, camera pictures, and commands. The current concept includes the use of communications relay transceiver 'pucks', which are dropped off in strategic distances during descent to perform a relay network for data transmission with the surface Lander. (see Figure A below)

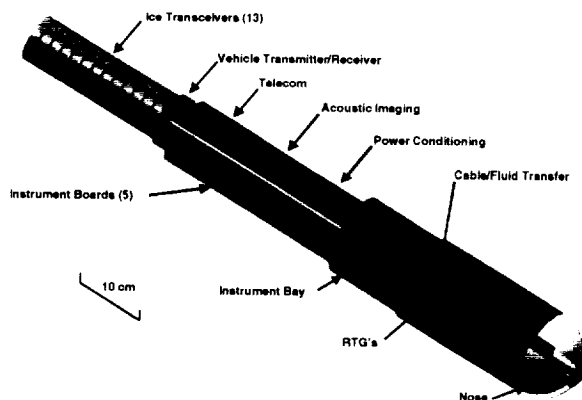


Figure A -- Cryobot Architecture

### **Submersible (Hydrobot)**

The submersible that will be used to roam the subsurface liquid ocean(?) shall be of Hydrobot design, and shall be capable of self navigation. Features of this HydroBot design/concept include (see Figure B):

- Advanced rad-hard silicon-micro-machined micro-IMU (containing three vibratory gyros and three vibratory accelerometers) with microprocessor, secondary power supplies, and self test/calibration circuitry on one MCM
- Two-axis velocimeter for subsea current measurements. Technology is electromagnetic with tiny shrouded propeller-generated voltage proportional to speed
- Sonar pinger transponder placed on sub-sea floor to serve as submarine range and bearing reference for periodic way-point update of the sub's inertial navigational system, and to ensure sub can find "home" again from science search sorties
- Pressure-equalized (silicone-fluid-filled) interface electronics for sensors, including velocimeter, forward-looking, and side-looking sonar
- Thruster-motor pressure-equalized (silicone-fluid-filled) drive electronics with motor-commutation and reversible-direction drives for brushless DC motors
- Sub-sea guidance and navigation algorithms for acoustic-aided, inertial-reference, dead-reckoning, on-sortie instrument calibrations, and topological way-point identification
- Communications of data and camera pictures with the Cryobot

Both Tethered and un-tethered concepts for a Hydrbot need further investigation to finalize the best solution and use of resources.



Figure B -- Hyrdobot in Operation (Artist's rendition)

### Communications Options and Approach

The issues associated with a mission to Europa are inherently driven by mitigation techniques used to avoid the intense radiation density that the Europa Orbit around Jupiter is constantly facing. To help with the mission concept, a preliminary determination to locate the Relay Orbiter outside the main radiation was assumed. Because of this choice, coupled with a two year mission goal to provide as much continuous communications coverage as possible, it was necessary to perform some trades to optimize the Relay location (distance from Jupiter and orbit type). This optimization really spawns two analysis sets:

(1) Communications coverage to/from Earth with a Europa Lander:

- Direct To Earth communications
- Relay communications from a Lander to a Relay asset around Jupiter

(2) RF Link analysis to determine performance capabilities given the goal to

transmit science data plus video back to Earth.

### Communications Coverage

This section presents communications coverage that demonstrates how long mission operators on Earth can communicate with the Lander on Europa or the Orbiter around Jupiter during mission lifetime. To obtain a good coverage, it is very important to choose an appropriate orbiter's orbit around Jupiter as well as an appropriate landing site for Lander. The coverage would vary with Lander's locations on Europa and Orbiter's orbital elements. With the Satellite Tool Kit (STK), various numerical scenarios have been developed for coverage analyses. For communications of Europa Lander mission, a communication link consists of Lander, Orbiter and three Deep Space Networks (DSN). It is assumed that the Lander would land on Europa's pole or equator, while Orbiter would orbit around Jupiter. When Lander is located on the equator of Europa, Lander always has same geometry with respect to Jupiter because Europa has synchronous rotation with its orbit. Thus, either Lander will always face toward Jupiter or Lander cannot always see Jupiter, according to its initial location. Hence, when Lander lands in Europa's equator, there are two typical landing areas, one area makes Lander face Jupiter, and the other area is far-side of Europa. Three DSNs on Earth are located at Canberra, Goldstone and Madrid. The Lander, Orbiter and three DSNs will communicate with each other or one another to transfer scientific data and control commands for Lander and Orbiter.

The Relay Orbiter can have an appropriate semimajor axis and eccentricity such that its orbital period is an integer multiple of Europa's orbital period around Jupiter. Then, geometry between Jupiter, Europa and Lander is periodic and predictable over long time periods, if we assume that

Orbiter's initial orbital elements can be kept for long time (sometimes, station-keeping maneuvers would be required.). All the orbits of the Relay Orbiter have orbital periods with an integer (N) multiple of Europa's orbital period (3.55 Earth days), and have either periapsis of 20 Jupiter Radii ( $R_J = 71,491$  km) or apoapsis of  $20R_J$ . The orbits were generated by the STK to include perturbations caused by the Sun and other planets. When  $N \geq 50$ , the orbits would be seriously perturbed by gravitational forces of other celestial bodies, especially the Sun. Consequently, the coverage would be unpredictable when N is large enough. The periapsis of each orbit for the Relay Orbiter is located toward Earth in order to make Lander on Europa see the Relay Orbiter as much as possible when Lander cannot see Earth directly. In the numerical simulations, initial orbital position of the Relay Orbiter is located at its true anomaly of around  $f \sim -90^\circ$ .

### **Communications Coverage results**

For constrained and perturbed cases, communications coverage of about 500~590 days (DTE + Relay) can be achieved for an equatorial Lander for a two year mission. Communications coverage of about 590 days (DTE + Relay) could be possible for a Polar Lander if the inclination and semimajor axis of the Orbiter Relay is large enough to accommodate the Lander limitations.

### **Communications RF link analysis results**

One important issue deals with communications performance and options regarding data transfers between Earth and the Lander (DTE or via Relay). The technology issue focuses on whether RF communications will suffice or should a push be made into the optical communications spectrum. The E<sup>3</sup>

concept for the most part assumes that RF communications is capable for the type of data rate transfers needed. However, after looking at what it may take to utilize RF communications, in the form of optimization and analysis, the idea of Optical communications lends merit.

There is not a unique RF communications configuration (i.e. power amplifier and antenna sizes) that will produce the minimum required link margins, rather there is connected set of possible configurations that satisfy the requirements. It is therefore desired to obtain a description of this feasible set of configurations rather than a single solution. Because of the unsuitability of classical root solving techniques for determining anything other than point solutions, another approach was necessary. Noting that this feasible set can be characterized by its boundary, namely the configurations that produce the minimum required link margins, the problem can be reduced to finding the hypercurve that describes this boundary. The determination of this boundary curve is complicated, however, by the fact that the link margins may not be at their required minima simultaneously. At one point along the boundary, the communications requirements between the relay and the Earth and between the lander and the Earth may be more stringent than those between the relay and the lander, at another point, the converse may be true. Because of this, the inequality constraints on the link margins cannot be replaced with equality constraints and the boundary cannot be traced point by point by a root solving technique. A mechanism that allows the specification of inequality constraints while forcing the solution to satisfy the constraints as close to bounds as possible was needed. These requirements suggest the use of constrained optimization techniques<sup>6</sup>. While the results are not necessarily optimal in any physical sense they are optimal in the sense that the constraints on the link margins are satisfied as closely as possible to their lower bounds.

**Table 2: Effect of Increased Comms. Power**

Power (W)	$D_L$ (m)	$P_L$ (W)	$\lambda_{L/R}$ (dB)	$\lambda_{L/E}$ (dB)
21	5.715899	27.26213	9.644125	3.000000
45	4.372711	46.58298	7.320082	3.000000
60	3.829268	60.74316	6.168247	3.000000
75	3.428191	75.78771	5.207802	3.000000
90	3.138947	90.39725	4.442489	2.999943
105	2.908838	105.2664	3.781528	3.000000
120	2.724004	120.0365	3.211495	3.000000
135	2.613108	135.0062	3.000000	3.149398

The computations used to determine the link margins were identical with those used within the **Spacecraft Performance Analysis and Simulation of Integrated Missions (SPASIM<sup>®</sup>)** software<sup>7</sup>. A data rate of ~ 1000bps is used for Command; 250,000 bps is used for telemetry, and it is further assumed that both the Lander and the Relay satellite use the same antennae for transmitting and receiving.

### **Optimization Results:**

An optimization using equal weighting of all parameter was performed first with the constraints specified. The optimization produced symmetric results with calculated antenna diameters of ( $D_L = D_R = \sim 5.72$  meters), and calculated RF amplifier power of ( $P_L = P_R = \sim 27.26W$ ). The corresponding link margins are  $\lambda_{L/R} = 9.644125dB$  and  $\lambda_{L/E} = \lambda_{R/E} = 3.000000$ . What this suggests is the use of a fairly large antenna (~5.72 meters) and relatively small power amplifier (~27.26 Watts).

Two points can be seen in these results. First, the communication requirements from the Jupiter Orbiting Relay satellite and Lander to Earth imposes the more stringent constraint, second, the

optimization favors increasing antenna diameter size over transmitting power. However, given the Lander configuration and potential issues with such a large deployable antenna on the surface, it is easier to look at increasing Power amplifier capability.

Table 2 presents the optimization results for the Lander. The results for the Jupiter Orbiting Relay satellite are symmetric with the Lander results and are not shown.

It can be seen that for power amplifiers larger than about 100 W the necessary diameter size drops below 3m. It is also interesting to note that as the antenna size decreases, the constraint on the link margin between the Lander and the Relay satellite becomes more dominant. Because of the concept to utilize nuclear power sources, increasing the Power amplifier seems the more logical approach than trying to sustain a ~5.7 meter antenna on the surface of Europa or in orbit around Jupiter. For this concept, utilizing current communications capabilities is consistent with a selection of a 3.0 meter antenna and a 135 Watt power amplifier.

### **RF Link analysis conclusion**

Utilizing a high power amplifier for both the Lander and the Relay Transmit

capability results in the decreased size need for an antenna. These values are all within the scope of current technology, given that the data rates remain nominal. However, if the true desire of the mission is to relay Video in HDTV or high resolution format without lossy compression techniques, data rates greater than 1-3 Mbps can be expected, and then the concept of the small antenna and 135 W power amplifier provide negative margin capacity. It is at this point that new technology RF systems, or *Optical Communications technologies* should be investigated<sup>4</sup>.

#### **Decision Tree software and technology database methodology**

The Jet Propulsion Laboratory has developed a software capability to aide in the decisions, ranking and technology paths taken towards the architecture and conceptual configuration of a mission. This software tool, though premature in it's completeness, relies on expert opinions, case history data and current state-of-the-art resources to categorize, rank and profile technologies that are chosen as architecture configurations and paths<sup>5</sup>. Then, depending on the optimum or selected path for the mission configuration, ranking statistics and relative costs are ordered and listed. Based on this Decision Tree usage, there still are some issues and points to be made about selections and decisions for the Europa Lander architecture.

When total funding is limited and needs to be carefully managed to achieve the highest probability of success of a Europa Life Detection mission, selection of the R&D portfolio becomes crucial. The study had to look for a way to structure decisions

to make them organized and easier to explain to others. For displaying the entire trade space, identification of all possible technical options, describing uncertainties, and weighing multiple options for analyzing performance, costs, and overall Figure of Merit/Probability of Success of the mission, the decision tree formulation is very useful. Below summarizes the benefits of such an approach. The complete tree for the Europa Life Detection Mission is quite extensive, ordered sequentially, listing technology options for Launch, Cruise, Orbital Entry & Descent, Surface & Subsurface Operations.

Technology options focused on power, communications, autonomy, survival, ice penetration, water submersion, and life detection.

- There are no single set of mathematical models available which describe the behavior of the complete system
- We can build decision trees and influence diagrams directly in an EXCEL spreadsheet, enter probabilities and payoffs directly in cells in a tree, and run a powerful decision analysis, including Monte Carlo simulation, on the resulting model to determine the best way to proceed with a technology R&D decision
- When we are faced with a set of alternative decisions, and to make decisions on funding R&D for new products, factoring in decisions at each stage of application and integration seems to make the best sense for overall project decisions

Mission objectives, and achievable performance metrics have been iterated with science teams; estimates of performances. and R&D costs at each link have been deduced and documented using information from NASA<sup>TM</sup>s Office of Space Science databases. These numbers are assumed to be the best estimates at present, which are continually being reviewed and updated by

the NASA domain experts at JPL, LaRC, and other centers.

### **Summary Description of Technology(s) areas to be investigated**

**Breakthrough** → Areas of performance & technologies that have been known to be a problem and have had continuous improvement efforts for years. Now, latest developments and activities have opened up possibilities to make these technologies accomplishable in the mission timeframe.

#### **(Breakthrough )**

- **Radiation Tolerant Electronics, Components, and Instruments**
- **In-situ (In Ice & Water) Sensing Components for Physical Science & Life Science Measurements**
- **In-situ(From Ice & Ocean) Resource Extraction, Sampling & Processing Hardware**
- **Reliable Components for Severe Environments. (Extremely cold and High Radiation)**
- **System-on-a-chip (e.g. inclusive of power management and distribution; (>4Mrad) )for Life Detection & Communications**
- **Miniaturized Communication components for data transfer through ice & water**
- **Miniaturized, integrated, and highly reliable Life Detection instruments, System on a Chip.**
- **Deep Ice Penetration: Low-mass, Power-efficient, & reliable Cryobot / Hydrobot / Tethered Submarine Assemblies**
- **Miniaturized, Integrated, and highly reliable, & autonomous Navigation hardware for the Cryobot / Hydrobot & Tethered Submarine**
- **Smart and reconfigurable transponders**

**Enabling** → Areas of performance & technologies that are crucial for success in the mission timeframe. Although technology acceptance and readiness levels may be low, funding and scheduling will provide these technologies for the mission.

- **Advanced Power: Safe radioisotope power sources, high-specific energy batteries (e.g. Li polymer),**
- **Advanced Chemical Propulsion (Lightweight engine, thrusters, lightweight tanks, warm gas pressurization) for descent**
- **Real-time autonomous descent, guidance and precision safe landing.**
- **Planetary Protection & Contamination: Sterilization of terrestrial contaminants (cleaning and measuring microbes).**
- **Thermal: Emphasis is thermal control on the surface ice; keep electronics warm, but do not melt through ice; thermal heat sources must be cooled during cruise; waste heat utilization**
- **Structures: multi-functional structures; electronic cabling modules integrated with structure**
- **Telecom: Spacecraft transponding modem, as well as solid state power for Ka-band**

The Europa Lander Decision Tree Model developed under the RASC sponsorship has provided an effective tool to address overall probability of success and cost of an example life detection mission to Europa by exploring alternative approaches by utilizing a variety of technologies. The study has resulted in identifying and rank ordering the top six (6) key technologies for R & D Funding (See Table 3):

- (1) Deep Ice Penetration,
- (2) Extended Survivability,
- (3) Life Detection,
- (4) Autonomous Hardware,
- (5) High-volume Communications,
- (6) and Thermal Control.

Further refinements and augmentation of the Decision Tree model are warranted to fully understand the R&D pay-offs of component-level technologies for achieving higher probabilities of success, and to explore options for communication through deep ice, improving survivability, life detection instrumentation packages, and occurrence of unexpected events.

**Table 3 – Technology Performance forecasts and Figures of Merit**

CAPABILITY	PERFORMANCE METRIC (Now/Required)	<i>Technical Challenges &amp; Breakthrough Technologies</i>
<b>Europa Surface Penetration</b>	0.005 (km)/ 3 to 4 (km)	Autonomous Operation in very Low-Temperature hard Ice & Ice/ Non-Ice Composite Material; <i>Motion, Intelligence, Navigation, Control, Sample Acquisition, Acoustic Image Interpretation of Complex Media, Communication</i>
<b>Extended Survivability</b>	0.04 (Yr.)/ 2 (Years)	Exposure to Intense Radiation (Several Mrads), Very Low-Temperature, and possibly Corrosive media, Very High Ambient Pressures; <i>Radiation Hardness, Adaptive Skin /Surface Treatment, Intelligent Thermal Control, AI for Dynamic Ice Environment, Liquid Filled Glass Ports (for the Submersible) to withstand pressure - kbars).</i>
<b>Life Detection</b>	200 (kg)/ 5 (kg)	Structure, Mass Distribution, and Morphology of Organics, Chirality of Molecules; <i>Automated Sample Handling/Routing, GC/MS with multi columns, HPLC, on-board ESEM, &amp; Raman Spectroscopy</i>
<b>Autonomous Hardware</b>	0.35 (# /4.26# DigOps /W-cm <sup>2</sup> )	Control, Robustness, Redundant AI Protocols; <i>In-situ processing of Science Data &amp; Reduction, AI for Data Storage, Feature Recognition, Robotic Sample Acquisition, Site Selection,</i>
<b>Communication</b>	10 (kbs)/100s (kbs)	High Data Rate & High Volume Communication through Ice/Non-Ice Composites, and Water, <i>Data Storage ~150 Mb, High Compression, Wide-area Transceivers, Autonomous,</i>
<b>Propulsion and Transit</b>	~10-100 Kg/KW/ ~4.4 Kg/KW	10-20 MT mass delivery to Jovian System; ~ 3 MT delivery to Europa Orbit; ~C3 of 90 for Europa (versus 16-25 for Mars); Mapper/Lander delivery to Europa after 1-2 months; Major Radiation Exposure; <i>Nuclear Propulsion technologies, low/high thrust technologies for use with planetary exploration; Nanofiber radiation protection technologies</i>
<b>Autonomous Hazard Detection and Avoidance</b>	50 km X 300 km (Mars) ~10 km (Moon) / .5 km (Europa)	Automatic re-direction of Lander during descent and adherence to landing within .5 km of targeted site; <i>Terrain imaging and processing, autonomous redesignation</i>



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